Solar Energy: A Short History

The beginnings of solar energy exploration began in the 1860s with Augustin Mouchot, who in 1866 developed the first parabolic trough solar collector as well as a steam engine powered by the sun. In 1921, Albert Einstein was awarded the Nobel Prize in physics for his research and discovery of the law of the photoelectric effect, which is a phenomenon in which electrons are emitted from matter after the absorption of energy from electromagnetic radiation such as X-rays or visible light. By 1953 the first silicon solar cell capable of generating an electric current was engineered, but it was not until a surge in oil prices in 1973 that the United States government began to invest in solar technology research. By the 1990s the costs of solar energy had dropped, but the costs of fossil fuels had also dropped. Therefore, solar was competing with a falling fossil fuel baseline.

Megawatts of Power

A megawatt (MW) is one million watts. While the amount of energy needed per home varies from state to state, and from home to home, according to the California Energy Center, one megawatt is enough electrical capacity to power 1,000 average California homes. (Assuming a loading factor of 0.5 and an average California home having a 2-kilowatt peak capacity.)[8] The loading factor is the ratio of actual electricity consumption in a large population. A loading factor of 0.5 means that 50% of homes are consuming all of the electricity that they are able or that, on average, all of the homes are only consuming 50% of the power they have the potential to consume. Peak capacity is defined as the maximum output an electricity generation source can produce at a given point in time.[9]

[8] http://www.consumerenergycenter.org/glossary/m.html

[9] http://neighborlysolar.com/blog/solar-economics/solar-and-modern-electric-utility-economics/

Cost per Megawatt of Solar Power

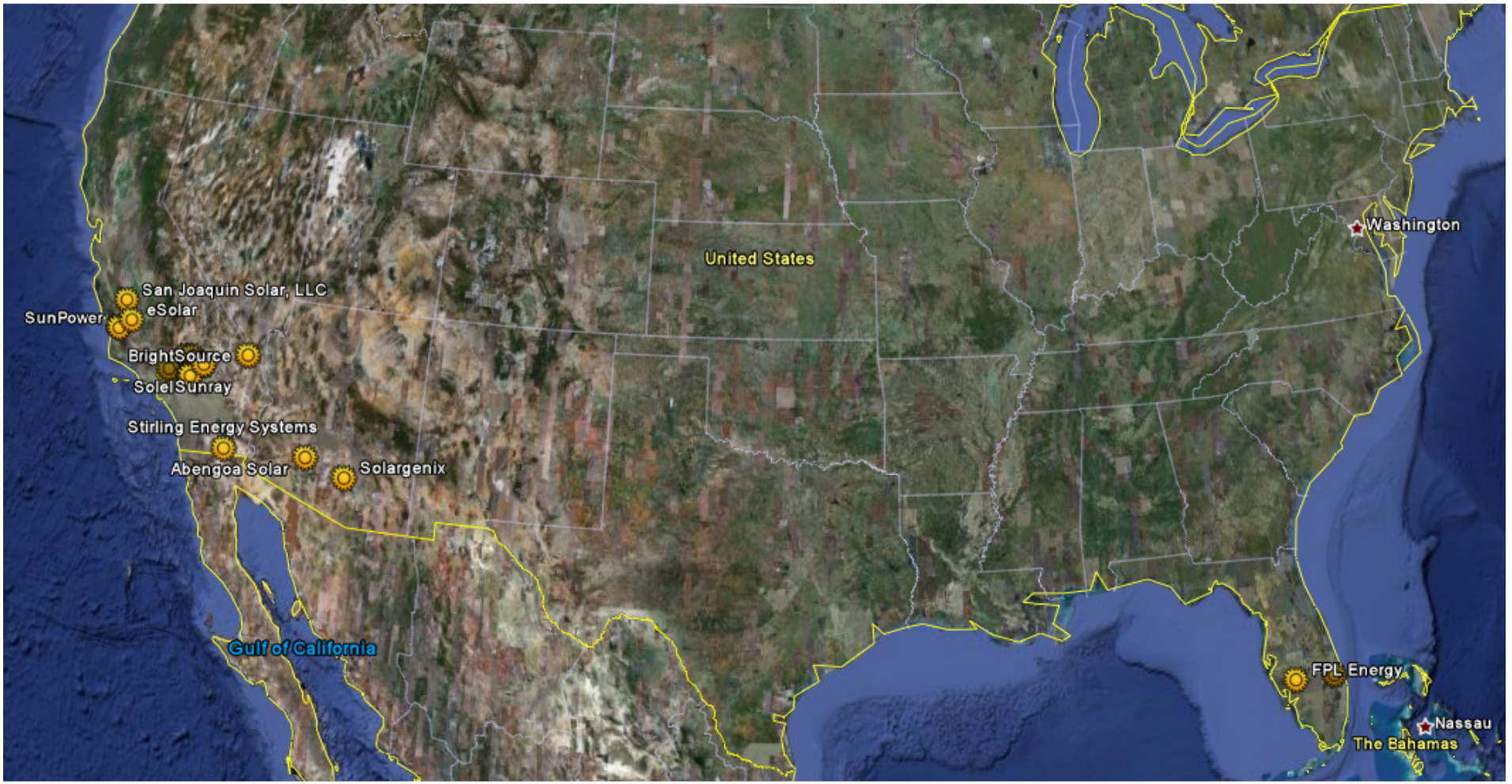
The chart presented on this page was taken from www.unernergy.org. Please note, estimates are included in this chart and the author did not cite any sources from which the existing information could be confirmed.

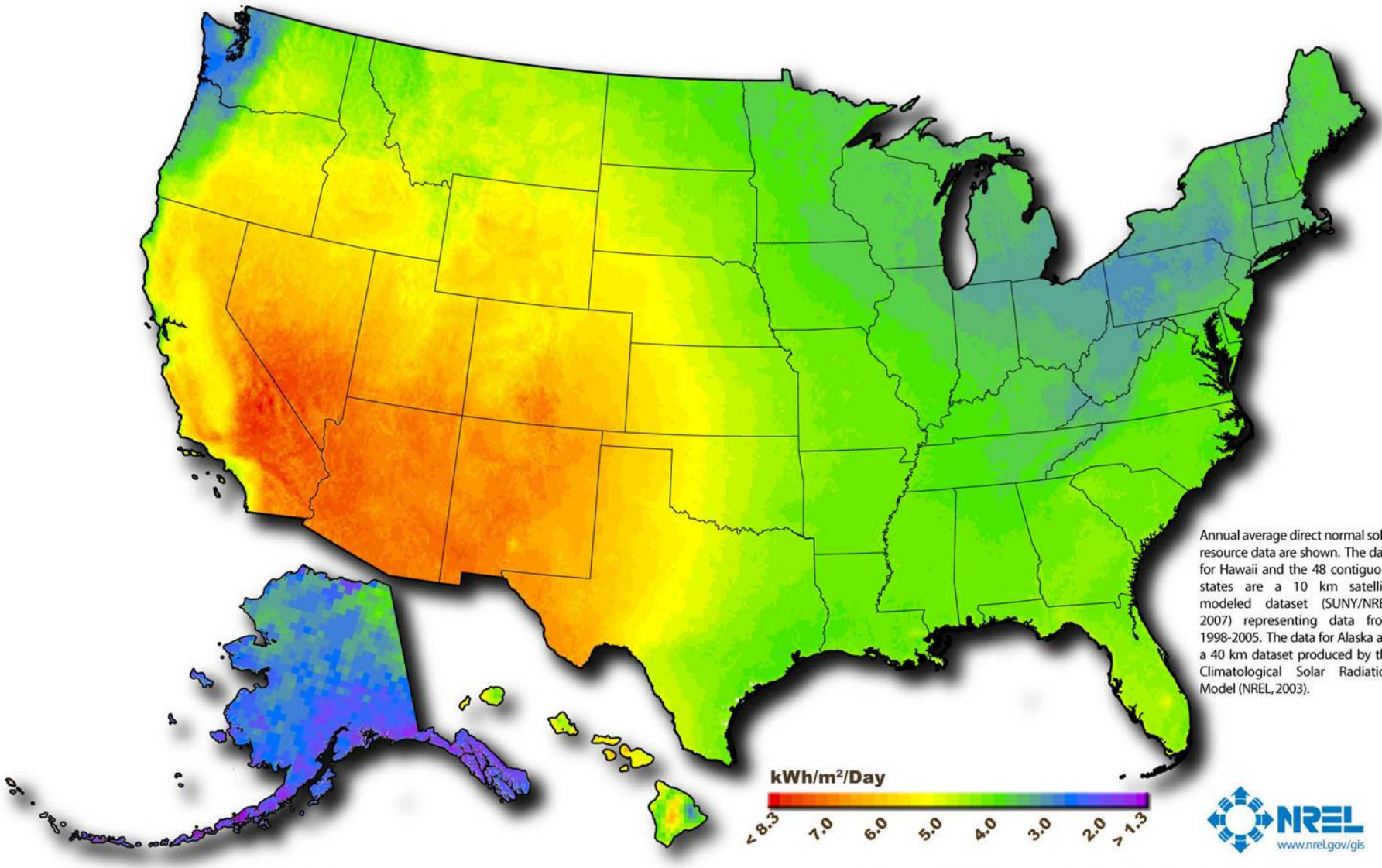
Electricity Generation costs estimates based on a single station developed with a prototype built and tested first.

Proposal	Coal Fired	Coal fired with 75% Geo-sequestration	Nuclear 2009 Estimate	Solar Tower 2009 Estimate	Combined Solar tower and PV panels	Geothermal steam	Wave Power	Concetrated Solar PV	Parabolic Concentrated Solar steam	Concentrated Solar Tower (steam)	Conventional PV	Wind Farms
Estimated life in years	25	25	25	60	60	15	30	15	15	15	15	25
Gross output	1000 MW/hr	1000MW/hr	1000MW/hr	200 MW/hr	350MW/hr	300MW/hr	200MW/hr	150MW/hr	200MW/hr	100MW/hr	100MW/hr	200MW/hr
Auxiliary use	50 MW/hr	200MW/hr	55MW/hr	5MW/hr	10MW/hr	15MW/hr	10MW/hr	5MW/hr	5MW/hr	5MW/hr	5MW/hr	10MW/hr
Mining, water, waste equivalent (MW/hr)	50 MW/hr	150MW/hr	130MW/hr	0	0	15MW/hr	10MW/hr	0	0	2MW/hr	0	0
Net output (MW/hr)	900	650	815	195	340	270	180	145	195	93	95	190
Output efficiency	90.00%	65.00%	81.50%	97.50%	97.14%	90.00%	90.00%	96.67%	97.50%	93.00%	95.00%	95.00%
CAPITAL COSTS												
Design Cost	$100,000,000	$500,000,000	$750,000,000	$150,000,000	$220,000,000	$250,000,000	$150,000,000	$150,000,000	$250,000,000	$150,000,000	$100,000,000	$100,000,000
Test Plant	Not required	$500,000,000	$1,000,000,000	$150,000,000	$250,000,000	$500,000,000	$250,000,000	$150,000,000	$250,000,000	$250,000,000	Not required	Not required
Materials/Equipment Cost	$700,000,000	$1,000,000,000	$1,000,000,000	$400,000,000	$500,000,000	$550,000,000	$600,000,000	$450,000,000	$600,000,000	$550,000,000	$750,000,000	$800,000,000
Construction Cost	$250,000,000	$500,000,000	$500,000,000	$250,000,000	$350,000,000	$350,000,000	$350,000,000	$250,000,000	$250,000,000	$250,000,000	$150,000,000	$300,000,000
Labor cost	$250,000,000	$400,000,000	$500,000,000	$90,000,000	$130,000,000	$200,000,000	$300,000,000	$190,000,000	$300,000,000	$200,000,000	$200,000,000	$150,000,000
Total capital Costs	**$1,300,000,000**	**$2,900,000,000**	**$3,750,000,000**	**$1,040,000,000**	**$1,450,000,000**	**$1,850,000,000**	**$1,650,000,000**	**$1,190,000,000**	**$1,650,000,000**	**$1,400,000,000**	**$1,200,000,000**	**$1,350,000,000**
OPERATIONAL COSTS												
Interest @ 6%	$78,000,000.00	$174,000,000.00	$225,000,000.00	$62,400,000.00	$87,000,000.00	$111,000,000.00	$99,000,000.00	$71,400,000.00	$99,000,000.00	$84,000,000.00	$72,000,000.00	$81,000,000.00
Fuel Cost	$200,000,000	$300,000,000	$400,000,000	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel/waste Disposal cost	$100,000,000	$250,000,000	$250,000,000	$0	$0	$30,000,000	$75,000,000	$0	$0	$0	$0	$0
Water use (including mining process)	$100,000,000	$150,000,000	$300,000,000	$250,000	$250,000	$15,000,000	$0	$0	$5,000,000	$5,000,000	$0	$0
Maintenance costs	$150,000,000	$250,000,000	$375,000,000	$10,000,000	$20,000,000	$50,000,000	$15,000,000	$25,000,000	$25,000,000	$25,000,000	$50,000,000	$100,000,000
TOTAL COSTS INCLUDING MINIMUM PRICE FOR CARBON												
C02 emissions including mining	1.35T per MW	0.6T per MW	0.4T per MW	0T per MW	0T per MW	0.15T per MW	0T per MW hour	0T per MW	0T per MW	0T per MW	0T per MW	0T per MW
Net C02 emissions (Tonne)	11,628,000	5,256,000	3,504,000	0	0	384,200	0	0	0	0	0	0
C02 cost at $50 per Tonne	$581,300,000	$262,800,000	$175,200,000	$0	$0	$19,710,000	$0	$0	$0	$0	$0	$0
Yearly running costs	$1,219,300,000	$1,386,800,000	$1,725,200,000	$72,650,000	$107,250,000	$225,710,000	$189,000,000	$96,400,000	$129,000,000	$114,000,000	$122,000,000	$181,000,000
Net yearly cost (life/capital) + running	**$1,271,300,000**	**$1,502,800,000**	**$1,875,200,000**	**$89,983,333**	**$131,416,667**	**$349,043,333**	**$244,000,000**	**$175,733,333**	**$239,000,000**	**$207,333,333**	**$202,000,000**	**$235,000,000**
Saleable MW produced in 1 year	7,884,000	5,694,000	7,138,400	1,708,200	2,978,400	2,365,200	1,576,800	1,270,200	1,708,200	814,680	832,200	1,664,400
Net cost per MW	$161.25	$263.93	$262.66	$52.68	$44.12	$147.57	$154.74	$138.35	$139.91	$254.50	$242.73	$141.19
Cost per kwh to produce	**$0.16**	**$0.26**	**$0.26**	**$0.05**	**$0.04**	**$0.15**	**$0.15**	**$0.14**	**$0.14**	**$0.25**	**$0.24**	**$0.14**
Current cost retail to consumer	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14	$0.14
Profit/Loss on installation based on market rates of 0.14c kw/h for 15 years	**-$2,513,100,000**	**-$10,584,600,000**	**-$13,135,260,000**	**$2,237,470,000**	**$4,283,390,000**	**-$268,730,000**	**-$348,720,000**	**$31,420,000**	**$2,220,000**	**-$1,399,172,000**	**-$1,282,380,000**	**-$29,760,000**
Yearly cost including capital repay	**$1,193,300,000**	**$1,328,800,000**	**$1,650,200,000**	**$27,583,333**	**$44,416,667**	**$238,043,333**	**$145,000,000**	**$104,333,333**	**$140,000,000**	**$123,333,333**	**$130,000,000**	**$154,000,000**
Life return	**$27,594,000,000**	**$19,929,000,000**	**$24,987,900,000**	**$14,348,880,000**	**$25,018,560,000**	**$4,966,920,000**	**$6,622,560,000**	**$2,667,420,000**	**$3,587,220,000**	**$1,710,828,000**	**$1,747,620,000**	**$5,825,400,000**
Life cost	**$29,832,500,000**	**$33,220,000,000**	**$41,255,000,000**	**$1,655,000,000**	**$2,665,000,000**	**$3,570,650,000**	**$4,350,000,000**	**$1,565,000,000**	**$2,100,000,000**	**$1,850,000,000**	**$1,950,000,000**	**$3,850,000,000**
Net return per annum	**-$89,540,000**	**-$531,640,000**	**-$650,684,000**	**$211,564,667**	**$372,559,333**	**$93,084,667**	**$75,752,000**	**$73,494,667**	**$99,148,000**	**-$9,278,133**	**-$13,492,000**	**$79,016,000**
Net return % per annum (No finance)	**-6.89%**	**-18.33%**	**-17.35%**	**20.34%**	**25.69%**	**5.03%**	**4.59%**	**6.18%**	**6.01%**	**-0.66%**	**-1.12%**	**5.85%**

Largest Proposed Solar Projects in the United States

The map below is a map of utility scale solar concentrating installations throughout the United States, with an obvious focus of product in Southern California, as the southwest has the highest concentration of peak sunlight hours (see heat map below). The solar projects in California are detailed below.





Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

NREL
www.nrel.gov/gis

Author : Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Largest Proposed Solar Projects in California

Project Name	Company/Developer	Location	Size (MW)	Type of Technology
SES Solar One Project	Stirling Energy Systems	San Bernardino County	850 MW	Stirling Engine
SES Solar Two Project	Stirling Energy Systems	Imperial County	750 MW	Stirling Engine
City of Palmdale Hybrid Gas-Solar	City of Palmdale	Palmdale, CA	617 MW	555 MW natural gas 62 MW solar trough
Victorville 2 Hybrid Power Project	City of Victorville	Victorville, CA	563 MW	513 MW natural gas 50 MW solar trough
Mojave Solar Park	Solel	San Bernardino County	553 MW	Solar Trough
Ivanpah Solar	Solar Partners/Brightsource	San Bernardino County	400 MW	Solar Tower
Mohave/Harper Lake Solar	Abengoa Solar Inc, LADWP	San Bernardino County	250 MW	Solar Trough
Project Genesis	NextEra Energy	Riverside County	250 MW	Solar Trough
Beacon Solar Energy Project	Beacon Solar LLC	Kern County	250 MW	Solar Trough
Solar Millennium Ridgecrest	Solar Millennium	Kern County	242± MW	Solar Trough
Solar Millennium Blythe	Solar Millennium	Kern County	242± MW	Solar Trough
Carrizo Energy Solar Farm	Carrizo Energy LLC	San Luis Obispo County	177 MW	Compact Linear Fresnel Reflector

SES Solar One/Two Project

This project is the sister project to the proposed Solar Two plant, to be located west of El Centro in Imperial County. The proposed SES Solar One project would be a nominal 850-megawatt Stirling engine project, with construction planned to begin in late 2010 if the project is approved by the California Energy Commission. The primary equipment for the generating facility would include 25-kilowatt solar dish Stirling systems, known as "SunCatchers", their associated equipment and systems, and their support infrastructure. Each SunCatcher consists of a solar receiver heat exchanger and a closed-cycle, high-efficiency Solar Stirling Engine specifically designed to convert solar power to rotary power then driving an electrical generator to produce grid-quality electricity.

The Solar Two project would be a nominal 750-megawatt Stirling engine project. The project will be constructed in two phases. Phase I of the project will consist of up to 12,000 SunCatchers configured in 200 1.5-MW solar groups of 60 SunCatchers per group, with a net nominal generating capacity of 300 MW. Phase II will add approximately 18,000 SunCatchers, expanding the project to a total of approximately 30,000 SunCatchers configured in 500-1.5-MW solar groups with a total net generating capacity of 750 MW.

The Solar Two project would include the construction of a new 230-kV substation approximately in the center of the project site, and would also be connected to the SDG&E Imperial Valley Substation via an approximate 10.3-mile, double-circuit, 230-kV transmission line. Other than this interconnection transmission line, no new transmission lines or off-site substations would be required for the 300-MW Phase I construction. The full Phase II expansion of the project will require the construction of the 500-kV

Sunrise Powerlink transmission line project proposed by SDG&E. The total area required for both phases, including the area for the operation and administration building, the maintenance building, and the substation building, is approximately 6,376 acres. The 230-kV transmission line required for Phase I would parallel the Southwest Powerlink transmission line within the designated right-of-way (ROW). A water supply pipeline for the project would be built on the approved Union Pacific Railroad ROW. Since the proposed project does not have a steam cycle, the primary water use would be for mirror washing.

City of Palmdale Hybrid Gas-Solar

The City of Palmdale proposes to construct, own, and operate the Palmdale Hybrid Power Project (PHPP or Project). The PHPP consists of a hybrid of natural gas-fired combined-cycle generating equipment integrated with solar thermal generating equipment to be developed on an approximately 377-acre site in the northern portions of the City of Palmdale. The combined-cycle equipment utilizes two natural gas-fired combustion turbine generators (CTG), two heat recovery steam generators (HRSG), and one steam turbine generator (STG). The solar thermal equipment utilizes arrays of parabolic collectors to heat a high-temperature working fluid. The hot working fluid is used to boil water to generate steam. The combined-cycle equipment is integrated thermally with the solar equipment at the HRSG and both utilize the single STG that is part of the Project.

The Project will have a nominal electrical output of 570 megawatts. If approved by the California Energy Commission, commercial operation of the project is planned for the summer of 2013. The solar thermal input will provide approximately 10 percent of the peak power generated by the Project during the daily periods of highest energy demand. The Project will be fueled with natural gas delivered via a new natural gas pipeline. The Southern California Gas Company will design and construct the approximately 8.7-mile pipeline in existing street rights-of-way within the City of Palmdale.

Victorville 2 Hybrid Power Project

On February 28, 2007, the City of Victorville submitted an Application for Certification (AFC) to construct and operate the Victorville 2 Hybrid Power Project (Victorville 2), a hybrid of natural gas-fired combined cycle generating equipment integrated with solar thermal generating equipment, in the City of Victorville, San Bernardino County.

The proposed Victorville 2 project would have a net electrical output of 563 megawatts (MW), with construction initially planned to begin in Summer of 2008, with commercial operation planned by Summer of 2010. Victorville 2 is designed to use solar technology to generate a portion of the project's output and thereby support the State of California's goal of increasing the percentage of renewable energy supplies. Primary equipment for the generating facility would include two natural gas-fired combustion turbine-generators (CTGs) rated at 154 MW each, two heat recovery steam generators (HRSGs), one steam turbine-generator (STG) rated at 268 MW, and 250 acres of parabolic solar-thermal collectors with associated heat transfer equipment. The solar-thermal collectors would contribute up to 50 MW of the STG's 268 MW output, and with plant auxiliary loads of about 13 MW, Victorville 2's net output would be 563 MW. The proposed Victorville 2 facility would connect via a single-circuit three-phase 230-kV transmission line to the power grid through Southern California Edison's (SCE's) existing Victor Substation, located approximately 10 miles south-southwest of the proposed Victorville 2 Project site.

Currently, the Victorville 2 project is the only solar project that has been approved in California. While construction was slated to begin in 2008, the City of Victorville has defaulted on payments to GE for the power turbines, and Inland Energy, the developers of the Victorville 2 Power Plant Project has not been able to obtain funding for development of the site. Much of the land has been assembled for this development, with appraisals conducted by Norris Realty Advisors. At present, there is not a Power Purchase Agreement in place for this project. As of July 13, 2009, the city council of Victorville was reviewing a new series of bids from power plant developers to acquire and develop the Victorville 2 Power Plant Project. Timing of completion is currently unclear.

Mojave Solar Park

The solar thermal project claims it will deliver enough power to supply 400,000 homes in northern and central California when it is fully operational. However, it will not be ready until 2011 as Solel, an Israeli company, is scheduled to break ground in mid-2009. It is to cover up to 6,000 acres, or nine square miles, in the Mojave Desert, relying on 1.2 million mirrors and 317 miles of vacuum tubing.

According to the California Energy Commission, as of June 25, 2009, the application for certification has not been filed. The cost of construction is slated to be around $2 billion.

Ivanpah Solar

This proposed project would be constructed in three phases: two 100-megawatt (MW) phases (known as Ivanpah 1 and Ivanpah 2) and a 200-MW phase (Ivanpah 3). The three plants are collectively referred to as the Ivanpah Solar Electric Generating System (ISEGS) and would be located in:

- Southern California's Mojave Desert, near the Nevada border, to the west of Ivanpah Dry Lake
- San Bernardino County 4.5 miles southwest of Primm, Nevada, 3.1 miles west of the California-Nevada border
- Township 17N, Range 14E, and Township 16N, Range 14E

Given that the three plants would be developed in concert, the proposed solar plant projects would share common facilities that will include access roads, and the transmission lines for all three phases. Construction of the entire project was anticipated to begin in the first quarter of 2009, with construction being completed in the last quarter of 2012, but as of June 25, 2009 the Ivanpah project was still under review, according to the California Energy Commission website.

Ivanpah 1, 2 and 3 would be interconnected to the Southern California Edison (SCE) grid through upgrades to SCE's 115-kV line passing through the site on a northeast-southwest right-of-way. Upgrades would include a new 220/115-kV breaker and-a-half substation between the Ivanpah 1 and 2 project sites. The existing 115-kV transmission line from the El Dorado substation would be replaced with a double-circuit 220-kV overhead line that would be interconnected to the new substation. Power from Ivanpah 1, 2 and 3 would be transmitted at 115-kV to the new substation.

Mojave/Harper Lake Solar & Project Genesis

While listed on the California Department of Energy's website as two of the largest proposed solar projects, no information could be found regarding either project beyond what is listed on the California Department of Energy website.

Beacon Solar Energy Project

Beacon Solar, LLC is proposing to construct, own and operate the Beacon Solar Energy Project. The project is a concentrated solar electric generating facility proposed on an approximately 2,012-acre site in Kern County, California. The project will use parabolic trough solar thermal technology to produce electrical power using a steam turbine generator (STG) fed from a solar steam generator (SSG). The SSG receives heated heat transfer fluid (HTF) from solar thermal equipment comprised of arrays of parabolic mirrors that collect energy from the sun.

The project will have a nominal electrical output of 250 megawatts (MW) and commercial operation is planned to commence by the third quarter of 2011, subject to timing of regulatory approvals and applicant achievement of project equipment procurement and construction milestones. The solar thermal technology will provide 100 percent of the power generated by the plant; no supplementary energy source (e.g., natural gas to generate electricity at night) is proposed to be used for electric energy production. The project will utilize two auxiliary boilers fueled by natural gas to reduce startup time and for HTF freeze protection. The auxiliary boilers will supply steam to the HTF freeze protection heat exchangers during nighttime hours to keep the HTF in a liquid state when ambient temperatures are not sufficient to keep the temperature of the HTF above its relatively high freezing point (54 degrees Fahrenheit). In order to fuel the boilers, a new 17.6-mile, eight-inch gas pipeline will be constructed to connect the project to an existing Southern California Gas Company (SCG) pipeline in the California City area. The project will also have a diesel fueled firewater pump for fire protection. As of June 25, 2009, this project had submitted its application for certification, and it was under review.

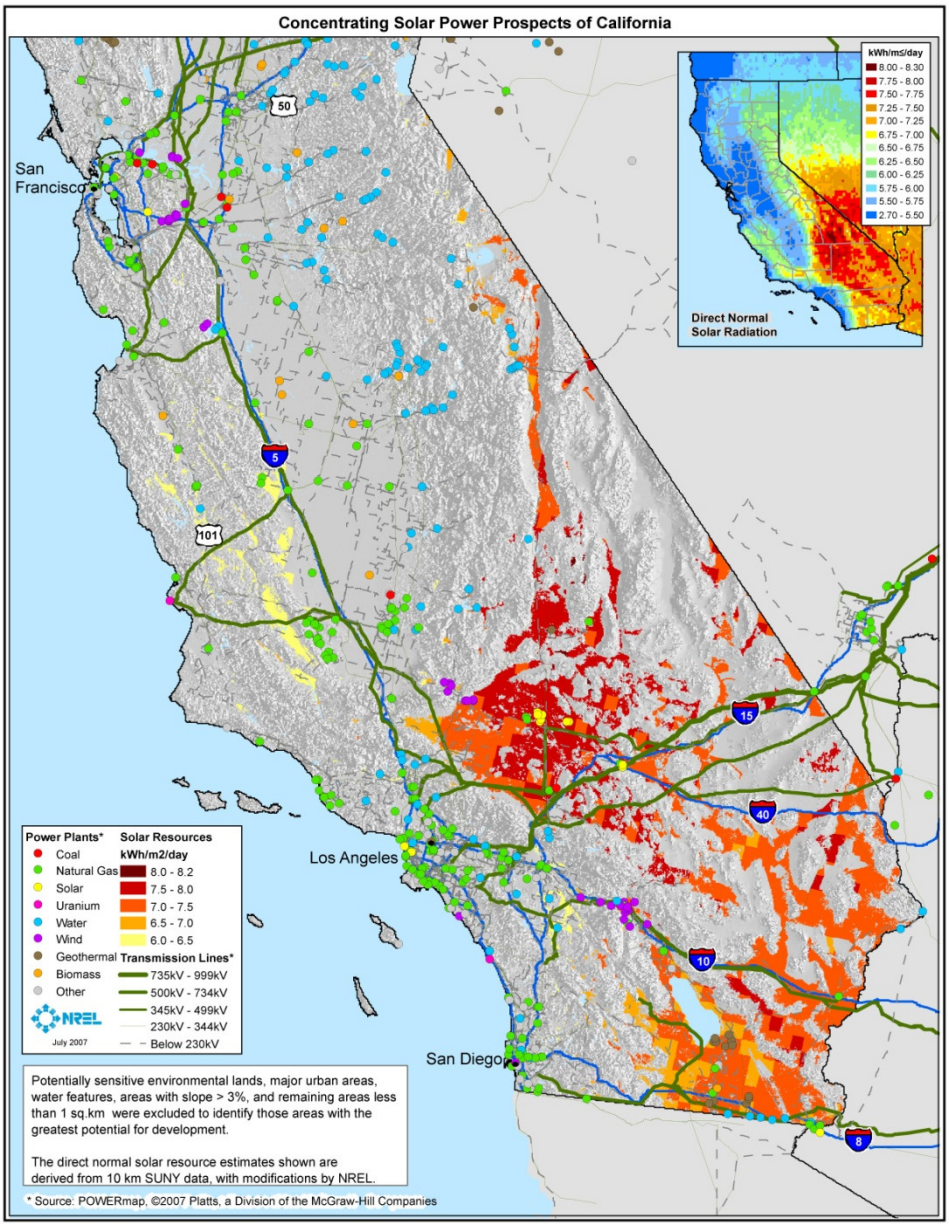
Solar Millennium Blythe/Ridgecrest

Solar Millennium, a German company, signed Power Purchase Agreements with Southern California Edison (SCE) for up to 726 megawatts of power from solar thermal and wind power suppliers. Solar Millennium's solar thermal plants will be located in Blythe and Ridgecrest, and will utilize solar trough technology. Each development from Solar Millennium will be a 242 MW power plant, with the option to expand to include a third 242 MW plant. Construction is planned to begin by the end of 2010, and speculated be ready to begin operations in 2013. Currently, the application for certification has not yet been filed.

Carrizo Energy Solar Farm

Ausra CA II, LLC has proposed to build the Carrizo Energy Solar Farm, which will consist of approximately 195 Compact Linear Fresnel Reflector solar concentrating lines, and associated steam drums, steam turbine generators, air-cooled condensers, and infrastructure, producing up to a nominal 177 megawatts net.

The project is located in an unincorporated area of eastern San Luis Obispo County, west of Simmler and northwest of California Valley, California. The Project design will incorporate Ausra's proprietary Compact Linear Fresnel Reflector technology to concentrate solar energy on pipes in an elevated receiver. If the license to construct is approved, construction of the project, from site preparation and grading to full commercial operation, is expected to take approximately 35 months. Site construction activities are slated to commence in the first quarter of 2009 and continue through the 35-month construction schedule. The project is scheduled to be online at partial capacity and available for dispatch into the grid on or before May 31, 2010. It is currently anticipated that the entire project will be online and in commercial service by the first quarter of 2012.



The project is estimated to cost approximately $550 million. It has encountered setbacks in the review process, as The Environmental Center of San Luis Obispo County was granted permission by the California Energy Commission to intervene in the licensing case for this project out of concern for the project's potential to harm sensitive wildlife species and plant communities through habitat degradation.

Federal Stimulus Involvement in Solar Power Plant Development[10]

The American Recovery and Reinvestment Act of 2009 provides increased funding, extended tax incentives, and outright grants to encourage renewable energy projects, energy savings, and green jobs.

For reference, a production tax credit is a reimbursement the federal or state government pays to companies that generate energy from renewable sources. An investment tax credit is a reimbursement for businesses that make new investments in renewable products and create new jobs in the industry.

Grants for Development of Renewable Energy Facilities

This section of the bill provides for grants of up to 30% of the cost of building a new renewable energy facility placed in service during 2009 and 2010 that would otherwise qualify for investment tax credits (ITC) or production tax credits (PTC).

Renewable Energy Loan Guarantees

Establishes a temporary Department of Energy loan guarantee program for renewable energy projects, renewable energy manufacturing facilities, and electric power transmission projects. Appropriates $6 billion to pay the credit subsidy costs, which is expected to support $60 billion of loan guarantees.

Investment Tax Credit in Lieu of Production Tax Credit

To address financing difficulties resulting from the uncertain future tax positions of potential investors in renewable projects, the bill allows taxpayers to elect to claim the ITC in lieu of the PTC for renewable energy facilities placed in service from 2009 through 2013.

Tax Credit for Investment in Advanced Energy

Provides up to $2.3 billion to fund a new 30% investment tax credit for investment in advanced energy facilities, such as facilities that manufacture components for the production of renewable energy, advanced battery technology, and other green technologies. Qualifying facilities must be certified by the Treasury Department, in consultation with the Department of Energy.

Repeal of State and Local Funding Penalty

Repeals the penalty for subsidized renewable energy financing, allowing businesses and individuals to qualify for the full amount of the investment tax credit, even if the project receives state or local subsidized energy financing.

Grid Modernization and Smart Grid Technology

Provides $11 billion in funding for modernizing the power grid and developing so called "smart grid" technologies.

Qualified Energy Conservation Bonds

Authorizes an additional $2.4 billion in bonds to finance state, municipal, and tribal government programs to reduce greenhouse gas emissions.

Clean Renewable Energy Bonds

[10] http://energypriorities.com/entries/2009/02/stimulus_legal_update.php

Authorizes an additional $1.6 billion of new clean renewable energy bonds to finance facilities that generate electricity from the following resources: wind, closed-loop biomass, open-loop biomass, geothermal, small irrigation, hydropower, landfill gas, marine renewable and trash combustion facilities.

Electric Transmission Infrastructure

Allows the Western Area Power Administration and the Bonneville Power Administration to borrow up to $3.25 billion to construct or finance transmission lines.

Solar Power Plant Water Consumption

Water consumption is an issue with concentrating solar power plants because they are most cost effective in locations where the sun is most intense, which in turn often corresponds to places where there is little water. California has excellent solar resources in the southern part of the state, but the availability of water has caused California to place restrictions on power plant water use.

According to a report by the U.S. Department of Energy, the four primary concentrating solar power technologies - solar trough, linear Fresnel, power tower, and dish-engine - all use water in different capacities. The first three of these technologies operate a steam cycle and require some water for steam makeup and, when they are water-cooled, require a substantial amount of water for heat rejection in a similar way to water-cooled fossil and nuclear plants. The dish-engine systems use the Stirling engine to directly produce electricity without producing steam. The Stirling engines are air-cooled, as their high operating temperatures allow high efficiencies without water cooling, and no water is needed other than for mirror cleaning. From a water use perspective, dishes are well suited for operation in regions with minimal available water. The table below outlines general guidelines for water consumption in power plants.

Table 2: Comparison of consumptive water use of various power plant technologies using various cooling methods

Technology	Cooling	Gallons / MWhr	Perform. Penalty*	Cost Penalty**	Reference
Coal / Nuclear	Once-Through	23,000 – 27,000***			1, 3
	Recirculating	400 - 750			1, 3
	Air Cooling	50 - 65			1, 3
Natural Gas					
	Recirculating	200			4
Power Tower	Recirculating	500 - 750			(estm.)
	Combination Hybrid Parallel	90-250	1-3%	5%	10, 11
	Air Cooling	90	1.3%		9
Parabolic Trough	Recirculating	800			5
	Combination Hybrid Parallel	100-450	1-4%	8%	7, Appx. A
	Air Cooling	78	4.5-5%	2-9%	6, 9
Dish / Engine					
	Mirror Washing	20			5
Fresnel	Recirculating	1000			(estm.)